SECTION 2

PROJECT OUTLINE

In order to improve the quality of stormwater runoff from its transit bases, the Municipality of Metropolitan Seattle (Metro) reviewed and reformed its stormwater best management practices (BMPs) in 1985 and 1986 (Horner et al. 1985, Kirchner 1986). Source control practices, emergency spill response plans, and runoff interception devices were investigated and implemented. Reforms in the stormwater BMPs at Metro's South Operations and Maintenance Base included not only source control measures but also the addition of two coalescing plate oil/water separators to the stormwater drainage system and the conversion of the stormwater retention pond into an artificial wetland.

The goal of converting the former dry detention pond into an artificial wetland was to raise the outflow water quality through the biofiltration and pollutant uptake action of certain wetland plant species (aquatic macrophytes). With funds from the Centennial Clean Water Grant of the Washington State Department of Ecology (Ecology), Metro researched the growth parameters and pollutant uptake potential of selected emergent aquatic macrophytes (emergents) in the constructed wetland (South Base pond) receiving stormwater runoff from Metro's South Base.

PROJECT GOALS AND OBJECTIVES

Through a more comprehensive understanding of the factors that influence aquatic plant growth and pollutant uptake, Metro hoped to achieve two broad goals:

- Contribute toward an expanded understanding of constructed wetlands as urban stormwater mitigators, especially on the regional level.
- Determine the applicability of constructed wetlands to Metro's own stormwater management program.

More specifically, the pond study sought to provide additional data on the effectiveness and desirability of emergent wetland macrophytes as accumulators of stormwater-related pollutants. Accordingly, research objectives were directed toward the following:

- Measuring pollutant uptake capacities in emergents by analyzing above- and below-ground tissues separately for lead (Pb), zinc (Zn), and total petroleum hydrocarbons (TPH)
- Correlating pollutant uptake capacities with standing crop biomass measurements, thereby gaining an estimate of pollutant removal potential of a given area on a per-species basis
- Monitoring seasonal variations in plant growth parameters along an elevation gradient to determine optimal hydrologic conditions for the species of interest

The results of this research could then be interpreted and formed into recommendations for the planning, construction, and management of artificial wetlands for stormwater mitigation in the Puget Sound region.

PROJECT ORGANIZATION

The pond project consisted of two related studies: pollutant uptake and plant vigor. The pollutant uptake study focused on the pollution uptake potential of several species of emergent macrophytes. The plant vigor study concentrated on associating factors of plant health (vigor) with relative elevation (inundation level) for several other species of emergents. Performed concurrently, the studies were chronologically organized into a synoptic phase and an intensive phase.

During the synoptic phase, the following occurred:

- The shoot, root, rhizome, and proximal soils (substrate) of ten species of aquatic macrophytes were analyzed for three stormwater-related pollutants that commonly result from motor vehicle use: lead, zinc, and TPH. Five species were then chosen for the pollutant uptake study during the intensive phase, on the basis of the initial analytical results showing elevated levels of the pollutants and on their observed successful establishment in the experimental wetland.

- Transects were established and individual plants were staked along an elevation gradient for the vigor study during the intensive phase.

- A water level recorder and a rain gauge were installed to monitor the frequency and duration of inundation at various elevations that may influence plant vigor and pollutant uptake.

During the intensive phase, the following occurred:

- Samples of five experimental emergents and associated substrates were taken in September and October and analyzed for lead, zinc, and TPH concentrations. Substrate levels of pollutants were monitored to gauge pollutant concentrations in plant tissues relative to their exposure levels. Plant tissues and substrates were analyzed in September for nitrogen and phosphorus content.

- To serve as controls, natural populations of the experimental emergents were located, sampled (once) and their substrates and tissues analyzed for lead, zinc, TPH, nitrogen, and phosphorus.

- Biomass plots of the five pollutant uptake species were harvested, dried, and weighed (once).

- Six emergent species were measured along transect lines at various inundation levels for height, basal diameter, inflorescence, and stem number on a seasonal basis. Four species that grew in clumps were measured for their elevational extremes.

- Daily precipitation and hourly pond water level data were taken to coordinate inundation frequency with plant vigor measurements.

SECTION 3

SITE BACKGROUND

This section contains a comprehensive description of the physical characteristics, historical background, and inflow sources of the South Base pond.

PROJECT LOCATION

Topographically a triangular, flat-bottomed basin with steep sides, the South Base pond occupies approximately 0.56 acres in the northernmost area of Metro's South Operations and Maintenance Base in a predominantly industrial/commercial area of Tukwila, Washington, south of State Route 599 (Interurban Highway). The pond location is shown in Figure 3-1.

The pond receives stormwater runoff from approximately 18.5 acres of asphalt, tar, and concrete surfaces from South Base, a maintenance and repair facility for Metro transit coaches, and the adjacent employee parking lot. Two inflows located opposite one another, one from the employee parking lot and one from the remaining South Base property, empty into the pond. The pond outflow lies approximately 20 feet from the South Base inflow and empties into a 30-inch open stormwater drain pipe that passes under State Route 599 into the Duwamish/Green River 0.4 miles east of the outflow (Figure 3-2).

Two earthen berms lengthen the retention time of stormwater inflow in the pond, one separating the South Base inflow from the outflow and another perpendicular to the parking lot inflow (Figure 3-3).

SITE HISTORY

The South Base pond was a former rock quarry that functioned as a dry detention pond intercepting and temporarily detaining stormwater draining from the paved surfaces of the base and the adjacent employee parking lot. Runoff entered the pond from two inflows, an unrestricted one from the employee parking lot and one from the base that was intercepted by a single API (American Petroleum Institute) oil/water separator. The pond outflow passed through another single API oil/water

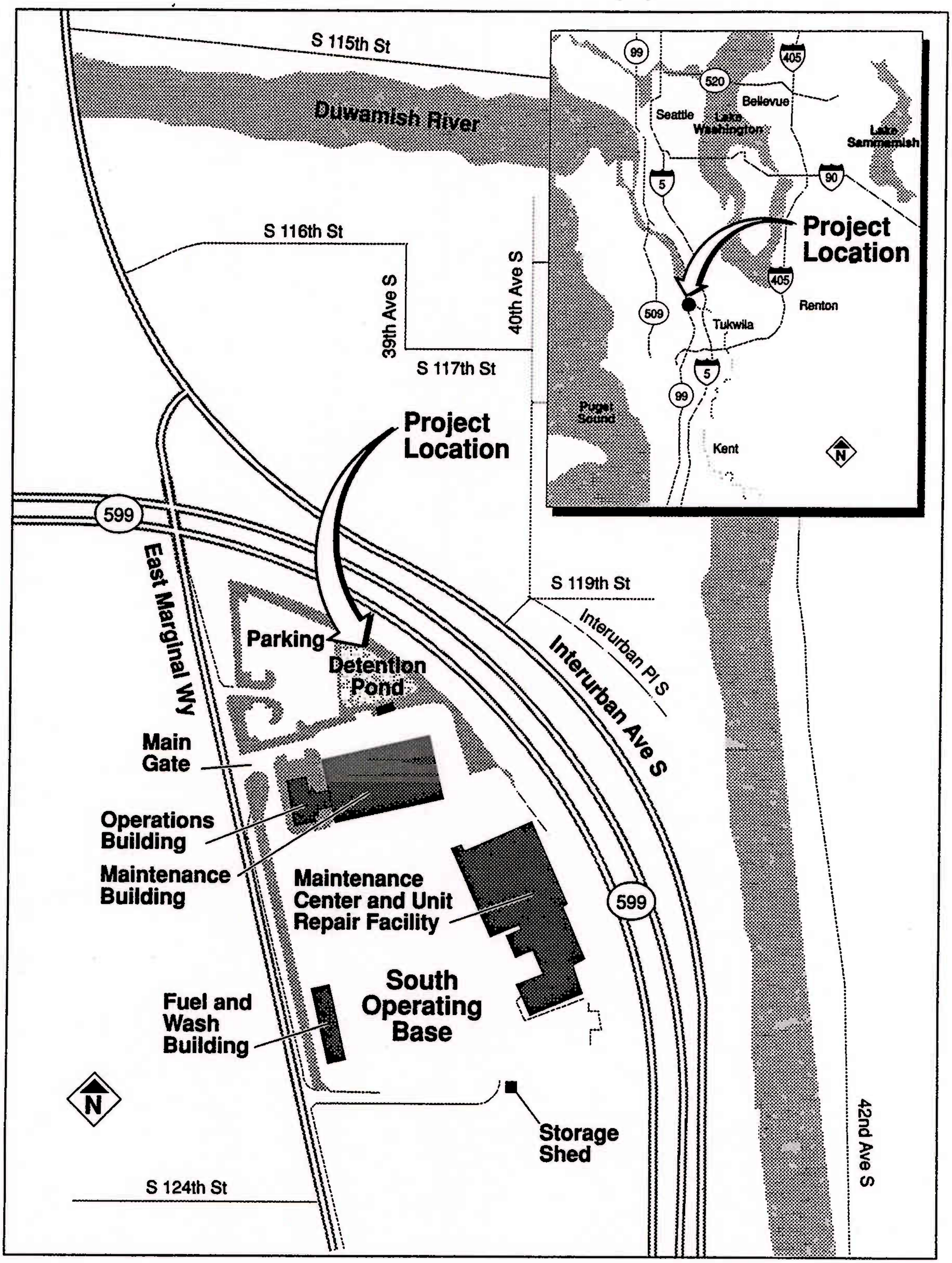

Figure 3-1. Project Location

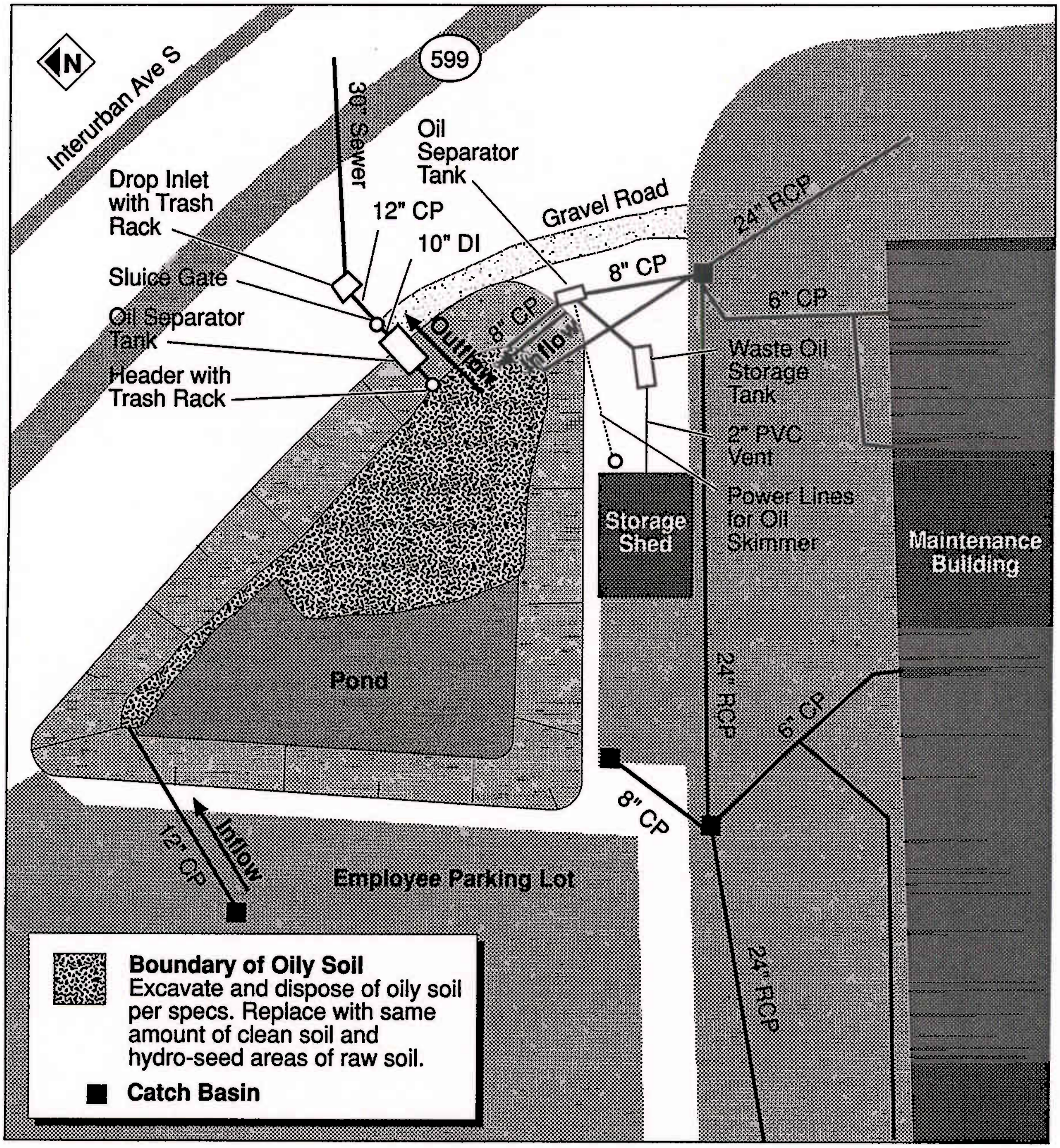

Figure 3-2. Pond Inflows and Outflow

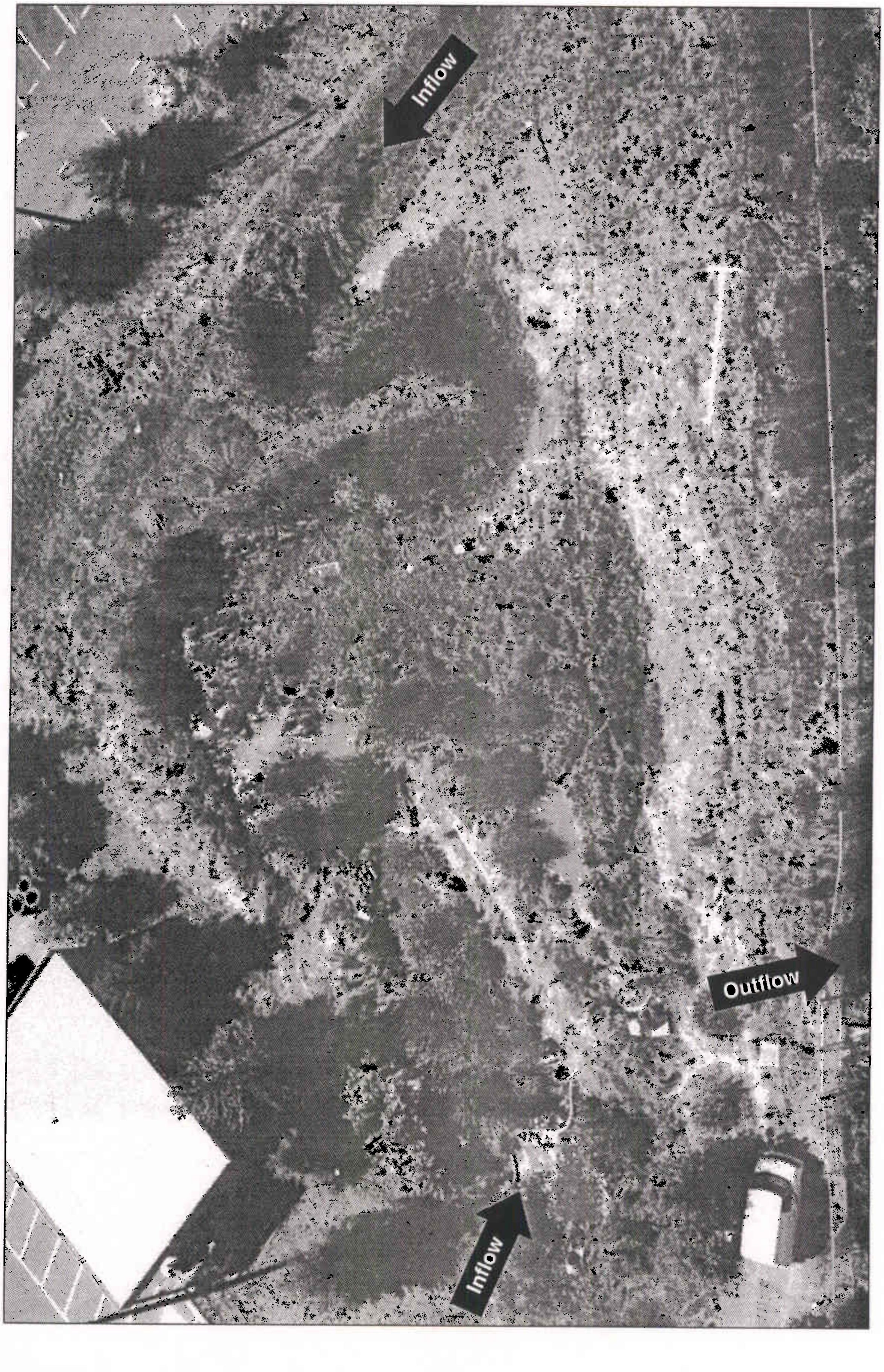

Figure 3-3. Pond Berms

separator and into a 30-inch open storm drain pipe that passed under State Route 599 and emptied into the Duwamish River.

Over the years, a pronounced sludge layer composed of oils, grease, soil, and other matter collected near the inflows. In February and March 1987, the Department of Ecology (Ecology), responding to anonymous complaints of oily discharge from the pond outflow, inspected the pond and placed it on its state list of contaminated sites because of high concentrations of petroleum hydrocarbons in the pond sediments.

Between June and September 1988, Metro removed approximately 300 cubic yards of contaminated sediments from the pond bottom as part of a program to come within environmental compliance limits (Figure 3-2). Tests rated the soil as nonhazardous waste, and it was approved to be disposed of at a local landfill. Later in the year, dual coalescing plate oil/water separators were installed above the pond, replacing the single API oil/water separator, in order to reduce oil and grease entering the pond from the paved areas of South Base Operations.

Also during 1988, structural modifications to the pond were initiated with the construction of a berm separating the base inflow and the outflow, which are approximately 20 feet apart. This berm was built to preclude the "short-circuiting" of flow and to increase hydraulic residence time to maximize pollutant removal through sedimentation of suspended solids. Concurrently, several wetland plant species were planted (Table 3-1) in shallow areas, and grass was hydroseeded on the pond banks to augment pollutant removal through biofiltration. As a result of these improvements, Ecology took the South Base pond off the state list of contaminated sites in April 1989.

In March 1991, the pond banks were determined to be too steep to support adequate vegetation for biofiltration and were regraded into a more gradual slope. The pond banks were reseeded with grass, and emergent wetland plant species were introduced to the regraded areas. A second, lower berm was also established near the employee parking lot inflow, and the outflow port was raised 6 inches. These modifications transformed the pond hydraulics into a meandering stream, further increasing hydraulic residence time.

To prevent surfactants from entering the stormwater drainage system, Metro employees were required to wash coach interiors inside the fuel/wash building, where wastewater is treated and recycled. They were also required to use a vinegar/bicarbonate soda solution instead of a detergent. These requirements were put in place in April 1991. Later that month, the South Base stormwater drainage system was thoroughly cleaned to remove silt accumulations.

TABLE 3-1. Selected Introduced and Volunteer Plants at South Base Pond					
Plant	**Introduced to Site**	**Volunteer on Site**	**Planted Nov. 1989**	**Planted March 1991**	**Experimental Plant**
Emergents					
Iris pseudacorus	✔		✔		✔
Typha latifolia	✔	✔	✔		✔
Eleocharis ovata	✔	✔	✔	✔	✔
Sparganium sp.	✔	✔	✔	✔	✔
Scirpus validus	✔			✔	
Scirpus acutus	✔		✔	✔	✔
Scirpus microcarpus	✔		✔	✔	✔
Scirpus cyperinus		✔			✔
Juncus effusus	✔	✔	✔	✔	✔
Juncus tenuis	✔		✔		✔
Juncus ensifolius	✔			✔	✔
Carex obnupta	✔		✔		
Upland					
Spirea douglasii	✔		✔		
Rosa nutkana	✔		✔		
Osmaronia spp.	✔		✔		
Prunus virginiana	✔		✔		
Sambucus spp.	✔		✔		

STORMWATER DRAINAGE SYSTEM

South Base's stormwater drainage system consists of a network of catch basins interconnected by concrete piping distributed throughout the paved region of the base. Areas lying below the level of the passive drainage system, such as loading docks, are serviced by catch basins fitted with sump pumps. Building roof gutters also feed into the stormwater drainage system. Runoff from precipitation contributes the largest volumes that enter the system. Infrequent spills, leaks, and overflow from sanitary sewers and water mains as well as groundwater seepage may account for a small fraction of the inflow volume. All wastewater produced at South Base is either recycled or passes into the sanitary sewers, and therefore does not contribute inflow to the pond.

SITE POLLUTION SOURCES

Metro's South Base, like all Metro facilities, has a pollution source control program designed to intercept potential pollution before it becomes a problem. This program includes careful handling of all potentially volatile and toxic substances, proper toxic waste disposal, quick emergency response to spills and leaks of hazardous compounds, and devices such as secondary containment tanks for fuel spills and oil/water separators that isolate oil and fuel waste from stormwater runoff. In spite of these precautions, the residues of occasional spills of compounds and fluids related to coach and facilities maintenance may contribute to stormwater pollutant loads.

Besides such isolated events, employee vehicles and transit coaches constitute the most significant and continuous likely sources of pollutants in stormwater runoff from South Base. Most vehicle-related pollutants such as lead, zinc, oil, and grease associate with road dust and often adhere to vehicle surfaces and become transported into the base.

In urban industrial areas similar to the South Base area, deposition rates of road dust can range from 1 to 3 pounds per acre per day (Asplund 1980). Transit coaches especially accumulate visible layers of oily soot and dust from their daily routes. Even though transit coaches receive regular washings, some portion of the introduced road dust inevitably falls and collects on the pavement or is washed off vehicles by rain and washed into the stormwater drainage system.

Oil, fuel, and other fluid leaks may provide other occasional sources of vehicle-related pollutants; however, Metro transit coaches undergo routine maintenance that precludes such problems. Employee vehicles may not receive such attention on a regular basis and can contribute crankcase oil and other leaking fluids to the stormwater pollutant load. South Base lies along heavily traveled Interurban Avenue and may also collect considerable road dust "fallout" that imports vehicle-related pollutants.

No water quality data exist for actual pond inflow samples that would give a more precise assessment of potential pollution sources for the South

Base pond. Speculation on potential pollution sources at South Base are based on analysis of pond sediments and observations of discoloration, odor, or sheen associated with inflow water.

SECTION 4

EXPERIMENTAL DESIGN AND METHODOLOGY

This section discusses the preparation, design, and methods of research of the South Base pond project.

Six species of emergents, three new to the site, were planted throughout the pond, especially in the regraded areas, in late March 1991. The plants were distributed in areas of both high (near inflows) and low (central area/outflow) pollutant exposure. Emergents planted in the newly regraded areas were placed at different elevations in the pond in order to expose them to various levels of inundation for the vigor portion of the study.

In late June/early July 1991, transects were established for the vigor study by staking and marking individual plants having their growth measurements monitored along the inundation gradient. A recording rain gauge and a Stevens water level recorder with a staff gauge were also installed to follow the changes in water depth with each rain event.

SYNOPTIC PHASE SAMPLING

On July 23, 24, and 25, 1991, ten species of aquatic macrophytes and their associated substrates were collected preferentially from high pollutant areas near the inflow pipes to maximize the probability of detectable pollutant levels. Three samples of each of the following species and their soils were taken: *Typha latifolia, Iris pseudacorus, Sparganium sp., Juncus ensifolius, Juncus tenuis, Juncus effusus, Eleocharis ovata, Scirpus acutus, Scirpus microcarpus,* and *Scirpus cyperinus*. Samples of mat-forming algae were also taken. Individuals were chosen from areas predominated by conspecifics to avoid variations caused by interspecific competition. The pond level was lowered to allow access to inundated sampling areas.

All sampling was performed using stainless steel utensils and gloves. The utensils and gloves were washed with a 1 percent solution of nitric acid and rinsed twice in deionized distilled water between all samples. Before harvesting the plants, a soil sample, consisting of three to five soil subsamples, was taken from the top 5 cm of the root zone around each plant and placed in a glass sample container provided by the analyzing laboratory. Plant tissues were harvested by first cutting the shoot from the roots near the soil surface and then extracting the roots and washing them in the pond to dislodge loose soil. The plant tissues were placed in plastic bags and stored on ice with the soil samples.

At the facilities lab, the plant tissues were prepared for transfer to the analyzing laboratory. Roots were washed repeatedly in containers of warm water that were replaced as the water became turbid. The roots were then rinsed under warm running water in a stainless steel sink. *Typha latifolia* and *Iris pseudacorus* roots and rhizomes were separated before processing. Dead tissue and inflorescences from shoots were removed, then the shoots were rinsed under warm running water and cut into 6-inch pieces. Finally, all plant tissues were rinsed in a 1 percent nitric acid solution and then rinsed three more times in deionized distilled water. Tissues were then placed in plastic sample bags, labeled, and stored on ice for transport to the analyzing laboratory.

All plant tissues and soils were analyzed for total petroleum hydrocarbons (TPH), zinc, and lead through a locally contracted testing laboratory. Plant tissues were dried at 70° C and soils were dried at 105° C. Plant tissues were analyzed for TPH by soxhlet extraction with freon for 8 hours. Soils were mixed with magnesium sulfate and sonication-extracted with freon three times for 10 minutes each time for TPH analysis. All tissue and soil extracts were then infra-red analyzed. All samples were tested for lead and zinc by microwave digestion methods and then analyzed by inductively coupled plasma (ICP) spectrophotometry. The lead analysis was redone later using a graphite furnace.

INTENSIVE PHASE SAMPLING

During the intensive phase, the research program developed during the synoptic phase was implemented to gather all data for the pollutant uptake and plant vigor studies. Biomass, rainfall, and pond water level data were also collected during the intensive phase.

Pollutant Uptake

Of the ten species sampled during the synoptic phase, *Typha latifolia, Iris pseudacorus, Eleocharis ovata, Scirpus acutus,* and *Sparganium sp.* were selected for study because the synoptic phase results indicated they had significant potential to remove pollutants and to produce substantial biomass per unit area.

There were two sampling events, September 5 through 17, 1991, and October 22 through 28, 1991. The September sampling consisted of collecting root, shoot, and soil samples from two controls and the experimental site. One set of controls came from the immersed potted plants in the pond; the other controls were obtained from natural, "uncontaminated" reference sites. *Sparganium sp.* was collected from the lower Cedar River. *Typha latifolia, Iris pseudacorus*, and *Scirpus acutus* were collected from the north end of Lake Sammamish near Marymoor Park. *Eleocharis ovata* could not be located at any of the natural sites and was acquired from a nursery. Only the experimental pond site was sampled in October.

The sampling methodology established in the synoptic phase was refined and modified for the September and October samplings. Samples were taken as follows:

- Seven samples of root, shoot, and soil from each of the five species.

- Four samples of each of the five species from the reference sites.

- Three soil and tissue samples from the *Typha latifolia* and *Sparganium sp.* potted controls and four soil and tissue samples from the Iris and Scirpus potted controls. *Eleocharis ovata* was not sampled from the potted controls because of senescence.

To reduce possible contamination through exposed tissues, plants were harvested intact rather than divided into root and shoot in the field. Plant roots were rinsed in the pond to removed contaminated soil, rinsed under a hose outside the lab, and rinsed again under warm running water in the lab. Tissues were then processed as in the synoptic phase; however, *Typha latifolia* and *Iris pseudacorus* roots and rhizomes were analyzed collectively as "root tissue" instead of dividing and analyzing them separately.

Chemical analysis of soil and tissue samples during the intensive phase followed the same methods as described in the synoptic phase methodology, except that an additional analysis for nitrogen and phosphorus was performed on all September control and experimental samples. Total phosphorus was analyzed colorimetrically using microwave digestion. Kjeldahl nitrogen was analyzed by digestion.

Biomass

Biomass measurements were gathered for each of the pollutant uptake species to estimate the pollutant removal capacity of a unit area of a certain species. Samples were harvested November 14 through 19, 1991. Areas of highest density for each species were preferentially chosen to gain an estimate of maximum production potential for each species. Three samples of one square foot or less were measured and harvested, both shoot and root, for each of the five pollutant uptake species. The samples were then rinsed thoroughly in warm water, bagged, labeled, and sent to the analyzing laboratory on ice for drying and weighing. All plant tissues were dried at 70° C and weighed to the nearest tenth of a gram.

Vigor

The monitoring of plant growth indicators for the vigor study was divided into two study groups according to species morphology. Six species, *Juncus effusus, Juncus tenuis, Juncus ensifolius, Scirpus microcarpus, Scirpus cyperinus*, and *Scirpus acutus* grow as identifiable individuals that grow outward from a basal meristem. Four species, *Typha latifolia, Iris pseudacorus, Sparganium sp.*, and *Eleocharis ovata* spread rhizomaceously, forming dense clumps without discernible individuals. Accordingly, different plant growth indicators were monitored for each group, with both sets of measurements designed to determine the preferred inundation level for each species.

From each of the six "individual" species, 20 plants were identified by numbered stakes along an inundation gradient. Each plant's elevation was determined from its base relative to the pond control water level, so that a foot of elevation represents a foot of water depth.

Height and basal circumference were measured and recorded in tenths of a foot using a cloth measuring tape and a yard stick. Numbers of inflorescences and stems were recorded depending on the species and season. Individual group measurements were taken seasonally from August 1991 to August 1992. Vigor measurements for all species were obtained August 15 and 16 and October 2 and 3, 1991, and on May 7 and July 29 through August 2, 1992. Basal diameter and height measurements for *Juncus effusus* and *Juncus ensifolius* were taken on December 16, 1991. Certain growth indicators were not measured for a time span or over the course of the study due to the absence or difficulty of measurement for that indicator. Basal circumference and height were the most consistently monitored growth indicator, while inflorescence and stem number were monitored only from spring to fall (Table 4-1).

TABLE 4-1. Individual Vigor Measurements Taken Per Species From August 1991 to August 1992

Species	Basal Circumference					Height					Inflorescences					Stems				
	Aug '91	Oct '91	Dec '91	May '92	Aug '92	Aug '91	Oct '91	Dec '91	May '92	Aug '92	Aug '91	Oct '91	Dec '91	May '92	Aug '92	Aug '91	Oct '91	Dec '91	May '92	Aug '92
Juncus effusus	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Juncus ensifolius	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	No	No	No
Juncus tenuis	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	No	Yes	Yes	No	No	No	No	No
Scirpus cyperinus	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	No	Yes	Yes
Scirpus acutus	No	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Scirpus microcarpus	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes

The expansion of a "clump" species was measured by marking the elevation of the clump boundaries with stakes at both the high and low extremes as the boundaries changed over time. Boundary elevations were established as they were for the individual species. *Typha latifolia* and *Sparganium sp.* were monitored at three sites each around the pond. Each site constituted a clump delineated by six stakes, three at each of the high and low edges. *Iris pseudacorus* was monitored in a single large clump with 12 stakes distributed evenly between the elevational extremes. *Eleocharis ovata* was monitored at two sites with six stakes apiece, distributed three each on the high and low edges. Boundary elevations were established October 31, 1991, and were subsequently remeasured May 13 and August 1, 1992.

POND HYDROLOGY

Both water level and rainfall data were taken over the entire study period from July 15, 1991, to August 27, 1992. A Stevens type "F" water level recorder was used to monitor the pond level continuously on a weekly basis. Water level was measured in tenths of a foot. The high and low levels for each day were entered on data sheets and eventually into a computer file. A staff gauge was also installed with the recorder at what was believed to be the lowest point in the pond, adjacent to the outflow. Later during the study, a lower point was found near the South Base inflow. Daily rainfall data were initially collected using a recording rain gauge; however, after persistent breakdowns, data were obtained from the National Weather Service at SeaTac airport, approximately 4 miles southeast of the study site. Daily rainfall was measured in fractions of an inch and recorded on data sheets and in the water level computer files. Trace precipitation was recorded as "zero" rainfall.

Several times during the study, the pond water level was artificially lowered with an eductor truck or raised using water hoses in order to measure plant elevations, take vigor measurements, and conduct pollutant sampling. The pond level was artificially raised in early October 1991 while the pond level was extremely low because of a drought that left many of the emergents visibly stressed.